Livelihood Benefits of Small Improvements in the Life Table

by Joel E. Cohen

This article proposes and illustrates a new lower bound on the economic benefits of reducing the number of deaths due to a particular cause and specifies the underlying economic and demographic assumptions. Unlike previous estimates of the increase in a population's output due to the extension of working lives, this new bound includes the present value to the existing population of avoiding future deaths from the cause. The estimated lower bound of $20 billion benefit from eliminating U.S. male deaths due to kidney and related diseases exceeds by an order of magnitude a previous estimate that considered only current deaths.

The economic justification of efforts to reduce human mortality depends on the patterns of costs and benefits of alternate (e.g., preventive or therapeutic) health activities. The economic justification of health activities generally, including efforts to reduce mortality, depends on their relation to other activities directed toward human welfare [1,2]. Assuming that it is necessary or desirable, at least under some circumstances, to justify economically efforts to reduce human mortality, or to use economic criteria as partial justification of a choice among alternate efforts to reduce mortality, this article attempts to clarify the assumptions and improve the rationality of one kind of such justification.

Comprehensive planning to reduce mortality takes account of all sources of mortality. This planning requires information about the reductions in mortality from each particular cause that would follow from alternate programs, as well as the costs of each of these programs. It is necessary to know what it would be worth economically to eliminate or reduce deaths from a particular cause.

An estimate of these benefits assumes nothing about the cost of eliminating the cause, nor even that it is technically possible to do so. An estimate, by itself, implies nothing about whether one should, on economic grounds, seek to eliminate that cause of deaths.

This article proposes new estimates of a lower bound on the economic

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Address communications and requests for reprints to Joel E. Cohen, Ph.D., Dr.P.H., Rockefeller University, 1230 York Ave., New York, NY 10021.

benefits of eliminating deaths from a particular cause in a human population, specifies the (limited) conditions under which these measures are appropriate, and illustrates them with data on U.S. male deaths from kidney diseases and related diseases of the urinary system.

The lower bound for which measures are proposed here estimates the increase in the economic output of a population due to the extension of working lives. Whether this increase is called a "direct" or "indirect" effect of the reduction in mortality seems to be a matter of convention [3–5].

These new measures differ from some in current use by including the present value to the existing population of avoiding future deaths from a specific cause and by distinguishing between curative and preventive benefits.

These new measures fall within the "livelihood" approach [6] to the valuation of changes in the probability of survival. As such, these measures are subject to some of the same criticisms that have been directed at previous livelihood valuations of life [7]. First, the expected present value of income of individuals may not reflect how the community values their lives. Second, livelihood measures ignore many externalities, positive and negative, of saving lives. Third, livelihood measures assume the justice, or economic rationality, of the observed distribution of income. Under circumstances to be spelled out below, these objections do not invalidate the use of livelihood measures as lower bounds on the economic benefits of changes in a population's survivorship, or life table.

This article is devoted to the improvement of these lower bounds, without denying the necessity for complementary alternate approaches to the valuation of the saving of lives.

ALTERNATE APPROACHES

Among the alternate approaches to the valuation of improvements in the probability of survival are three considered by Acton [7] and a fourth suggested by George T. Feiger (personal communication, April 14, 1973).

First, obtaining explicit statements of the economic value of lives saved from a politically responsible person is not a workable approach because it is usually difficult to identify such a person [7]. If he is identified, he is usually reluctant to announce a fixed valuation.

Second, inferring the value of saving lives from the evaluations implicit in past decisions is an unreliable guide to present action because these evaluations may well not remain constant over time or in new circumstances and because an extremely wide range of values can be inferred [7].

Third, asking what institutions in the private capital market would lend on the basis of the improved expected present value of lifetime income is impossible because there are no institutions that make loans of this kind or that pool the risks involved in insuring lifetime income. There are no such institutions because, among other reasons, the underlying problem has not been solved of finding incentives to keep people working once their lifetime income is insured (Feiger, personal communication).

Finally, asking people what they are willing to pay for improvements in probabilities of survival yields results that are subject to bias by: people's difficulty in understanding and using information about uncertainty, particularly when small probabilities are involved; people's strategies of revelation, particularly their hesitancy to say that they would pay for a common good that would improve their probabilities of survival even if they did not pay for it; and the particular form of questions and questionnaires used to elicit willingness to pay [7].

Acton's empirical investigation of willingness to pay yielded a valuation of avoiding a death from heart attack that was almost identical to that obtained from a livelihood approach. There is unfortunately too little other experience to suggest how general this concordance is.

A LOWER BOUND

It is important to emphasize that the new measures proposed here omit some economically important benefits of reducing the number of deaths from a cause. Notwithstanding, the reason for presenting these measures is that the lower bound they establish is substantially larger than that established by some previous livelihood measures.

The measures make no attempt to consider the value of "life" saved, but only the benefits of "livelihood" saved. Although the measures offer new ways of estimating the number of years of life saved, they neglect the value per se of these years. The measures allow nothing for nonwork activity. Hence the measures cannot be used in, and are not equivalent in purpose or function to, the imputation to the measure of economic growth for changes in life expectancy proposed by Usher [8].

The measures make no attempt to consider the reduction in anticipatory anxiety about the risk of death, the loss of pleasure from gambling with small risks of death, or the reduction in consequential grief over the fact of death that may accompany the saving of lives [6].

The measures neglect any reduction in output or earning capacity as a result of morbidity that may precede death from the cause.

The measures sidestep completely the production (net of consumption or gross) and years of life of individuals not yet born. This ex ante point of view restricts the accounting of benefits to an existing population that is called upon to make decisions regarding its future. This view avoids a potentially infinite stream of benefits to an increasing population and the necessity of introducing a pure time preference [1] even for noneconomic benefits. As a consequence of this ex ante point of view, these measures are neither intended nor suitable for use in the economic evaluation of birth control programs, a task replete with its own difficulties [9].

ECONOMIC ASSUMPTIONS

The measures proposed make economic assumptions that limit the circumstances in which they should be applied.

The measures assume that the economic value of livelihoods is reflected in age-specific (and possibly sex-specific) average incomes. This assumption may restrict the applicability of the measures to economies with enough land and capital and high enough employment that average incomes are a good index of the marginal product of labor. This assumption may also make the measures irrelevant to economies in which institutional and familial arrangements keep productive labor out of markets.

An important consequence of this assumption for application of the measures is that age-specific average incomes should be chosen that exclude any form of income that would not be altered by the death of the individuals receiving it, such as some inheritances and rents.

The measures assume that the individuals whose lives would be saved would receive the age-specific *average* income. Thus the measures assume that the cause of death and the means of preventing it have no bias towards abnormally productive or unproductive individuals within each age class.

These measures assume the beneficiaries of reducing the number of deaths from a cause to be both the population of survivors (those who would live whether or not the cause were eliminated) and the individuals presently alive who would otherwise die from the cause. They thus produce ex ante estimates of economic benefit rather than ex post estimates of insurance that ought to be carried for the surviving population. The measures therefore do not deduct from income the discounted consumption of the individuals who would die if the cause were not reduced [10].

The measures assume that the reduction of deaths from the cause will not substantially change the age distribution of age-specific average incomes, the overall rate of growth of incomes (which may be zero), or other important economic parameters in the measures. Thus the measures are embedded in a larger (tacit) partial equilibrium analysis [3]. It is in this sense that the changes in the life table considered here are "small."

The measures assume that it is possible to define and estimate a discount rate that is an appropriate blend or balance of the opportunity cost of capital and social time preference and that this discount rate is uniformly applicable to the entire population [1,11].

DEMOGRAPHIC ASSUMPTIONS

The measures proposed also depend on certain demographic assumptions.

The measures concern statistical deaths that would appear as a result of a change in a population's life table rather than the deaths of specified individuals known in advance [6].

The measures assume that, except for the specified reduction in mortality, there are no other simultaneous changes in the life table.

The measures ignore any demographic consequences of the shift in age composition of the population as a result of saving lives other than changes in the number of individuals in each age class. For example, the saving of lives that increases the dependency burden is assumed to have no effect on the labor force participation rate of individuals of parental age.

The mortality rates used are both age-specific and cause-specific because they are estimated from the causes reported on death certificates. The way the following calculations use these rates presupposes that the cause of deaths whose reduction is being considered acts age-specifically and independently of other causes of deaths. The individual saved from the specified cause is assumed to face thereafter neither greater nor lesser risk of death from that or any other cause.

This assumption can be violated because the cause no longer acts in a strictly age-specific way after an individual has once been saved from death due to it and because other causes of death subsequently fail to act independently.

Measles and myocardial infarction are both examples of causes of death that do not act strictly age-specifically after a first nearly lethal attack. An individual just saved from death from measles usually (barring a rare hereditary defect) has a lifelong immunity to the disease. An individual who suffers a myocardial infarction but whose death is prevented probably stands a greater future risk of a recurrent attack and death than an individual of equal age with no prior attack.

Superimposed bacterial infection actually causes most deaths attributed to measles. If deaths from bacterial infection were accurately recorded, then an individual saved from death from measles proper might face increased risk of death from bacterial infection. Here the assumed independence between measles and other causes of death would be false.

In the following, when I speak of eliminating a cause of death or of eliminating mortality due to a particular cause, I do not necessarily assume that *all* deaths from the cause are eliminated unless the numerical values of the mortality rates used so indicate. The measures proposed remain useful when only part of the deaths from a cause are eliminated, although the numerical example given assumes that all deaths from the specified cause(s) are eliminated.

CURATIVE AND PREVENTIVE BENEFITS

Although the preceding confession of assumptions and omissions, disclaimers, and qualifications is not usually recited, it is appropriate to, but does not uniquely specify, the measure used by Rice [4], Hallan et al. [5], and others to evaluate part of the potential benefits of health programs due to the elimination of mortality from a particular cause. Their measure is based on Farr's formula for the expected present value of future earnings of a man of a given age, as modified by Barriol to apply to gross income [12]. Their measure estimates the gain in expected present value of future earnings that would accrue to a population if each individual who died in the current time period (e.g., this year) from the cause were restored to life and henceforward subjected to the chances of survival specified in his population's present life table.

One shortcoming of this measure as an evaluation of the economic benefit of a potential cure for deaths from this specific cause is that it includes only the potential benefits of avoiding the deaths that occur during the *current* time period and neglects the (present discounted) benefit to the population presently alive of deaths avoided years in the future. I propose a measure, called the *curative* benefit of eliminating a cause of deaths, to correct this omission.

The curative benefit assumes that an individual who is, for the first time, on the point of death from the cause is restored to the risks of death (including death from the cause) that are the current average for his age. As in the presently used estimate of the benefits from reductions in mortality, he would be assumed *not* to be cured if death from the cause approached a second time. Thus the curative benefit estimates the economic value in terms of increased productivity to the population now alive of giving each individual in the population exactly one chance to be cured of the cause of death whenever it may strike during the remainder of his life.

A second obvious shortcoming that this curative benefit shares with the measure presently used is just this assumption that each individual gets only one chance to be cured. If the risk of death from the cause is eliminated once and for all from the entire population, then an individual who would have risked death from the cause a second, third, or fourth time is saved from all those risks. I propose a measure, called the *preventive* benefit of eliminating a cause of deaths, to take account of the shift in the life table of the entire population when the risk is eliminated completely.

To make the curative benefit explicit mathematically, I introduce some terms and notation. The present state of affairs, before elimination of the cause of death, is called "before"; the state of affairs after elimination is called "after."

Both before and after, assume that the highest age to which anyone survives is ω, that the instantaneous rate of discounting is D, and that the instantaneous rate of growth of income [13], the same for all ages, is g. Let age x vary continuously from 0 to ω; let $K(x)$ be the number (density) of individuals of age x in the present population and $u(x)$ be the present average income per unit time (i.e., average wage times employment rate) of individuals of age x.

Before (elimination of the cause of deaths) let $n(x)$ be the proportion of individuals born who survive at least to age x, with $n(0) = 1$, and let $\nu(x)$ be the instantaneous force of mortality in the population. (The usual actuarial notation for $n(x)$ is $\ell(x)$.) Let

$$\nu(x) = \mu(x) + \lambda(x) \tag{1}$$

where $\mu(x)$ is the instantaneous force of mortality after elimination of the cause of deaths and $\lambda(x)$ is the force of mortality associated with the cause. If, after, $m(x)$ is the proportion of individuals born who survive at least to age x and $m(0)=1$, then (with $0 \leqslant x \leqslant \omega$ and $0 \leqslant x+\tau \leqslant \omega$)

$$\frac{n(x+\tau)}{n(x)} = \exp - \int_{x}^{x+\tau} \nu(z)\, dz \tag{2}$$

and

$$\frac{m(x+\tau)}{m(x)} = \exp - \int_{x}^{x+\tau} \mu(z)\, dz \tag{3}$$

Take the present as time 0. The expected *present* value of earnings of a man who is aged $x+\tau$ at a time τ in the future is, before elimination of the cause,

$$e^{(g-D)\tau} \int_{t=0}^{\omega-x-\tau} e^{(g-D)t} \frac{n(x+\tau+t)}{n(x+\tau)} u(x+\tau+t)\, dt \tag{4}$$

The exponential factor in front of the integral discounts the expected capitalized value of the man's earnings while allowing for growth between time τ and the present. Within the integral, the ratio $n(x+\tau+t)/n(x+\tau)$ is the probability that the man would live from age $x+\tau$ to age $x+\tau+t$, and the rest is the income he would earn then, as affected by growth and discounting.

Now the expected number per unit time of individuals in the population currently living who will die at age $x+\tau$ at time τ in the future due to the specified cause is simply

$$K(x)\frac{n(x+\tau)}{n(x)}\lambda(x+\tau) \tag{5}$$

since a man aged $x+\tau$ at a time τ in the future is aged x now. Hence the curative benefit C of eliminating the cause is the product of Eqs. 4 and 5, integrated over all ages x in the present population and all future times τ for which each of the present cohorts will not have vanished:

$$C = \int_{x=0}^{\omega} K(x) \int_{\tau=0}^{\omega-x} \frac{n(x+\tau)}{n(x)} \lambda(x+\tau) \int_{t=0}^{\omega-x-t} e^{(g-D)(t+\tau)} \times \frac{n(x+\tau+t)}{n(x+\tau)} u(x+\tau+t)\, dt\, d\tau\, dx \tag{6}$$

For each value of τ, change variables from t to $z=t+\tau$, then interchange the order of integration (adjusting the limits of integration) of the two inner integrals in Eq. 6. The result may be written:

$$C = \int_{x=0}^{\omega} K(x) \int_{z=0}^{\omega-x} e^{(g-D)z} u(x+z) \frac{n(x+z)}{n(x)} C(x,z)\, dz\, dx \tag{7}$$

where the kernel $C(x,z)$ on the right is

$$C(x,z) = \int_{\tau=0}^{z} \lambda(x+\tau)\, d\tau \tag{8}$$

The *preventive* benefit to a population P, as described above, of the elimination of a cause of deaths is the difference between the entire expected present value of the population's income after eliminating the cause and the entire expected present value of the population's income before. Explicitly,

$$P = \int_{x=0}^{\omega} K(x) \int_{z=0}^{\omega-x} e^{(g-D)z} u(x+z) \left[\frac{m(x+z)}{m(x)} - \frac{n(x+z)}{n(x)} \right] dz\, dx \quad (9)$$

where the term $m(x+z)/m(x)$ in square brackets gives a man's probability of survival from age x to age $x+z$ after and the term $n(x+z)/n(x)$ gives the probability before.

The preventive benefit as expressed in Eq. 9 may be rewritten:

$$P = \int_{x=0}^{\omega} K(x) \int_{z=0}^{\omega-x} e^{(g-D)z} u(x+z) \frac{n(x+z)}{n(x)} P(x,z)\, dz\, dx \quad (10)$$

where the kernel $P(x,z)$ on the right is

$$P(x,z) = \frac{m(x+z)}{m(x)} \Big/ \frac{n(x+z)}{n(x)} - 1 \quad (11)$$

Clearly the curative benefits (Eq. 7) and preventive benefits (Eq. 10) differ only in their kernels, Eqs. 8 and 11. Comparing these gives, with the use of Eqs. 2 and 3, an appealing result:

$$P(x,z) = e^{C(x,z)} - 1 \quad (12)$$

Since $C(x,z) \geqslant 0$, $P(x,z) \geqslant C(x,z)$ and the inequality is strict whenever $C(x,z) \neq 0$. When the curative kernel $C(x,z)$ is small with respect to 1, a power series expansion of the right side of Eq. 12 shows that the curative and preventive kernels nearly coincide. However, even small differences in the kernels are subject to amplifications by Eqs. 7 and 10. Thus an ounce of prevention may be worth a pound of cure.

In the simplest case, in which all forces of mortality in Eq. 1 are independent of age x, $\omega = \infty$, $u(x) = u$, and $K(x)$ is the stable age distribution of a population with total size K, Eq. 7 becomes

$$C = \frac{K\lambda u}{(g-D-\nu)^2}$$

and Eq. 10 becomes

$$P = \frac{K\lambda u}{(g-D-\nu)(g-D-\mu)}$$

To guarantee that the integrals in Eqs. 7 and 10 exist, it is necessary and sufficient that $g - D < \mu$. The values of C and P are independent of the intrinsic rate of natural increase of the stable population. Clearly $C < P$ when $\mu < \nu$.

The inner integrals in Eqs. 7 and 10 are functions of x and may be called, respectively, $C(x)$ and $P(x)$, the curative and preventive benefits to an individual of age x. The aggregate curative and preventive benefits C and P are then sums of these age-specific benefits weighted by the population at each age. A standard age distribution of population might be used in place of $K(x)$ in order to compare the elimination of different causes of death in different populations.

If $u(x) = 1$ for all x, and if the dimension of $u(x)$ is changed from dollars to years, and if $g - D = 0$ in Eqs. 7 and 10, then C and P measure the curative and preventive years of life saved. Feldstein [1] remarks

> The basic justification for discounting future increments to consumption is that the marginal utility of consumption falls as per capita consumption rises. This reasoning provides no justification for discounting future non-dollar benefits such as lives (or years of life) saved.

Hence $g - D = 0$. $C(0)$ measures the increase in expectation of life at birth if each individual is given one chance to verge on death from the specific cause and be restored to the present (before) risks of death of his cohort. $P(0)$ measures the increase in expectation of life at birth if each individual is subject from birth to all causes of death save the specified one.

This interpretation, in terms of years of life saved, eliminates some of the more odious economic assumptions made above and adds a dimension that is widely considered to be important to the benefits of eliminating a cause of deaths.

KIDNEY AND RELATED DISEASES: AN EXAMPLE

An example illustrates the magnitudes of and differences between the curative and preventive benefits, age-specific and aggregate, in terms of both dollars and years of life saved. The example is deaths from kidney disease and related diseases of the urinary system in the entire male population of the United States in 1964. The magnitude of the specific risk of death, the population at risk (excluding females), and the economy are chosen to maximize the extent to which the economic assumptions are fulfilled.

For the ages used in the traditional abridged life table, Table 1 shows the actual (before) probabilities of survival from the beginning of one age interval to the beginning of the next interval, the fractions of deaths within each age interval due to causes other than kidney and related diseases, and the probabilities of survival after. These probabilities of survival before and after determine the years of life saved according to the curative and preventive measures, also shown in Table 1. According to these estimates, preventive elimination of deaths from kidney and related diseases would increase the expectation of life at birth by 0.63 yr; curing moribund patients the first time they verged on death from kidney or related diseases would increase the expectation of life by 0.61 yr, in a population with the 1964 U.S. male life table. The average preventive benefit to the 1964 U.S. male population would be an increase in life of 0.54 yr, and the average curative benefit would be an increase of 0.53 yr.

Based on an estimate of $u(x)$ from 1963 data, Table 2 shows the expected

Table 1. Probabilities of Survival for U.S. Males in 1964 Before and After Hypothetical Elimination of Mortality (Middle Estimate) due to Kidney Diseases and Related Diseases of the Urinary System; Curative and Preventive Years of Life Saved

Age	Probability of survival before	Deaths from other causes	Probability of survival after	Years of life saved		
				Curative	Preventive	Preventive/curative
Under 1	0.9729	0.9988	0.9729	0.61	0.63	1.0245
1–4	0.9953	0.9691	0.9960	0.61	0.63	1.0247
5–9	0.9974	0.9355	0.9976	0.61	0.62	1.0249
10–14	0.9974	0.9305	0.9975	0.60	0.61	1.0251
15–19	0.9934	0.9490	0.9937	0.59	0.60	1.0254
20–24	0.9908	0.9526	0.9912	0.57	0.59	1.0259
25–29	0.9910	0.9438	0.9915	0.56	0.57	1.0264
30–34	0.9892	0.9532	0.9897	0.54	0.55	1.0269
35–39	0.9851	0.9691	0.9855	0.53	0.54	1.0273
40–44	0.9769	0.9804	0.9774	0.53	0.54	1.0276
45–49	0.9633	0.9243	0.9661	0.50	0.51	1.0282
50–54	0.9412	0.9493	0.9441	0.45	0.47	1.0293
55–59	0.9099	0.9620	0.9132	0.42	0.44	1.0303
60–64	0.8687	0.9695	0.8724	0.41	0.42	1.0308
65–69	0.8073	0.9373	0.8182	0.37	0.38	1.0308
70–74	0.7413	0.9440	0.7538	0.30	0.31	1.0295
75–79	0.6548	0.9401	0.6716	0.23	0.23	1.0259
80 and over	0.5269	0.9222	0.5538	0.11	0.11	1.0164
			Total	49537000	50849600	1.0265
			Per capita	0.53	0.54	1.0265

curative and preventive benefits to income (in 1963 dollars) by age, in aggregate and per capita, for annual discount factors of 1 (that is, no discounting), 1.02, 1.04, and 1.06. Each discount factor may be written $1 + i$ and is consistent with any combination of instantaneous discount rate D and growth rate g such that $\log(1 + i) = D - g$. The curative benefit to a newborn ranges from \$1747 with no discounting ($i = 0$) to \$90 with six-percent discounting ($i = 1.06$); the preventive benefit ranges from \$1764 to \$90. Increasing the discount rate shifts the distribution of benefits toward the older ages because younger males have longer to wait before they enter the years of earning. Even at six-percent discounting, the aggregate preventive benefit of eliminating deaths from kidney and related diseases is nearly \$20 billion; the average per capita benefit is \$213.

Table 3 estimates the range of uncertainty in these calculations. Summary statistics from Tables 1 and 2, which are based on an estimated 54 765 male deaths in 1964, are given under the heading "Middle estimate." The corresponding summary statistics are also given in Table 3 for a low estimate of the 1964 male deaths due to kidney diseases and related diseases of the urinary system, totalling 32 553, and for a high estimate, totalling 94 411. Over the range from low to high estimates and from no discounting to six-percent dis-

Table 2. Present Value for Various Discount Rates of the Increase in Output due to the Extension of Life

Age	Present value			Present value		
	Curative benefit ($)	Preventive benefit ($)	Preventive/ curative	Curative benefit ($)	Preventive benefit ($)	Preventive/ curative
	DISCOUNT FACTOR: 1			DISCOUNT FACTOR: 1.02		
Under 1 ..	1746.93	1764.13	1.0098	586.49	590.86	1.0074
1–4	1735.06	1752.25	1.0099	608.77	613.34	1.0075
5–9	1706.39	1723.42	1.0100	650.25	655.19	1.0076
10–14	1664.96	1681.75	1.0101	693.85	699.19	1.0077
15–19	1599.91	1616.34	1.0103	724.21	729.94	1.0079
20–24	1502.83	1518.77	1.0106	731.25	737.32	1.0083
25–29	1393.71	1409.11	1.0110	725.81	732.21	1.0088
30–34	1291.57	1306.43	1.0115	721.20	727.95	1.0094
35–39	1211.51	1225.95	1.0119	729.85	737.02	1.0098
40–44	1157.75	1171.91	1.0122	757.81	765.51	1.0102
45–49	988.93	1001.82	1.0130	687.97	695.53	1.0110
50–54	739.63	750.51	1.0147	534.10	540.88	1.0127
55–59	556.22	565.70	1.0170	416.25	422.57	1.0152
60–64	436.94	445.49	1.0196	340.75	346.90	1.0180
65–69	319.48	326.13	1.0208	260.67	265.78	1.0196
70–74	190.51	194.57	1.0213	160.96	164.24	1.0204
75–79	97.72	99.75	1.0208	85.35	87.09	1.0204
80 and over ...	20.76	21.10	1.0164	17.90	18.19	1.0164
Total (in thousands)	117584000	118899000	1.0112	57685600	58230700	1.0094
Per capita	1251.02	1265.01	1.0112	613.74	619.54	1.0094
	DISCOUNT FACTOR: 1.04			DISCOUNT FACTOR: 1.06		
Under 1 ..	218.18	219.39	1.0055	89.63	89.99	1.0041
1–4	236.16	237.48	1.0056	100.98	101.39	1.0041
5–9	273.07	274.61	1.0057	126.01	126.53	1.0042
10–14	317.24	319.07	1.0058	158.72	159.40	1.0043
15–19	357.26	359.40	1.0060	191.58	192.44	1.0045
20–24	383.77	386.23	1.0064	216.60	217.67	1.0049
25–29	403.02	405.84	1.0070	237.74	239.05	1.0055
30–34	425.02	428.25	1.0076	263.18	264.80	1.0062
35–39	460.61	464.35	1.0081	303.03	305.07	1.0067
40–44	517.24	521.63	1.0085	366.33	368.94	1.0071
45–49	496.28	500.89	1.0093	369.59	372.51	1.0079
50–54	397.53	401.88	1.0110	303.95	306.83	1.0095
55–59	319.03	323.35	1.0135	249.87	252.88	1.0121
60–64	270.36	274.86	1.0167	217.88	221.24	1.0154
65–69	215.39	219.37	1.0185	180.01	183.15	1.0175
70–74	137.22	139.91	1.0196	117.94	120.16	1.0189
75–79	75.03	76.53	1.0199	66.34	67.64	1.0196
80 and over ...	15.47	15.72	1.0164	13.41	13.63	1.0164
Total (in thousands)	32110600	3274500	1.0082	19841100	19986900	1.0073
Per capita	341.64	344.45	1.0082	211.10	212.65	1.0073

Table 3. Summary of Benefits Resulting From Hypothetical Elimination of Mortality Due to Kidney Diseases and Related Diseases of the Urinary System for 1964 U.S. Males, Based on Low, Middle, and High Mortality Estimates

Benefit	Low estimate		Middle estimate		High estimate	
	Total male pop.	Per capita	Total male pop.	Per capita	Total male pop.	Per capita
Years of life saved at birth						
Curative		0.4		0.6		1.1
Preventive		0.4		0.6		1.1
Average years of life saved						
Curative		0.3		0.5		1.0
Preventive		0.3		0.5		1.0
Present value in dollars						
DISCOUNT FACTOR: 1						
Curative	78 billion	848	118 billion	1251	210 billion	2233
Preventive	80 billion	854	119 billion	1265	214 billion	2281
DISCOUNT FACTOR: 1.02						
Curative	39 billion	418	58 billion	614	103 billion	1093
Preventive	40 billion	420	58 billion	620	105 billion	1113
DISCOUNT FACTOR: 1.04						
Curative	22 billion	233	32 billion	342	57 billion	608
Preventive	22 billion	234	32 billion	344	58 billion	618
DISCOUNT FACTOR: 1.06						
Curative	14 billion	144	20 billion	211	35 billion	376
Preventive	14 billion	145	20 billion	213	36 billion	381

counting, the estimated aggregate benefit to the male population of the U.S. in 1964 of preventing all future deaths due to these diseases ranges from $14 billion to $214 billion and the estimated per capita benefit ranges from $145 to $2281. The estimated increase in expectation of life at birth ranges from 5 to 13 months.

The Appendix describes in more detail the sources of data and methods used to prepare the three tables.

COMPARISON WITH A PREVIOUS ESTIMATE

The middle estimate of aggregate curative benefit obtained here with six-percent discounting exceeds by a factor of 22 the total indirect cost of male mortality estimated from the same deaths with the same discounting by Hallan et al. [5]. Without the increase in estimated incomes from 1963 to 1964 (see Appendix), the difference in estimated benefits would be even larger. It is worth making clear three reasons for this large difference.

First, the curative benefit is a one-time, lump-sum benefit representing the entire present value to the population now alive of saving individuals from the cause of death the first time it threatens. Hallan's measure (identical with that used by Rice [4] and others) is a current measure of this year's share of a stream of benefits. (However, calculating the total present value of Hallan's stream of benefits would not give the benefit estimated by the curative measure for the remaining reasons.)

Second, the curative measure includes the benefit next year of reduced mortality to the individuals now alive who would otherwise be dead from the cause, whereas Hallan's measure applied to next year's population omits the individuals who die this year from the cause.

Third, the curative measure omits all benefits to individuals not yet alive who will be born in the future. Hallan's measure, applied to next year's population, includes benefits to individuals not yet born. This difference between the aggregate curative measure and Hallan's measure diminishes, rather than augments, the difference between them. Presumably the present value of benefits to unborn individuals could be imputed to their parents, although the question is unclear [10]. If the intrinsic rate of natural increase of the population exceeded the discount rate, the present value of the benefits imputed to each parent would be infinite.

In view of these three differences, the curative measure as expressed in Eq. 5 could be obtained by discounting to the present the stream of benefits obtained from applying Hallan's measure to future populations containing only and all those individuals now alive who would have suffered zero or one attack of the cause of death in question. The preventive measure could not be obtained by such adjustments of the population because it is based on a changed life table.

Perhaps the principal virtue of the measures proposed here is that they provide an improved lower bound of the benefits that would accrue to the population now called upon to make a decision regarding its own future.

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APPENDIX

High, middle, and low estimates of the number of deaths of (white and nonwhite) males in the U.S. in 1964 due to kidney diseases and related diseases of the urinary system were based on unpublished tabulations of the U.S. National Center for Health Statistics. The middle estimate was obtained by distributing the deaths estimated in Table 7-23 of Hallan et al. [5] into the smaller age categories of the usual abridged life table, assuming a uniform distribution of deaths within the broader age intervals used by Hallan et al. The high estimate was obtained by summing within each age group all male deaths in the NCHS tabulations in any of the ICD classifications listed by Hallan et al. [5] or by Hallan and Harris [14]; only ICD classifications N866 (injury to the kidney) and N867 (injury to the pelvic organs), which were omitted from the tabulations available to me, are not included. The low estimate was obtained by weighting each category by its percent of deaths with irreversible uremic involvement (estimated by medical consultants; see ref. 14, pp. 214–215); again categories N866 and N867 were omitted.

The numbers of deaths of all U.S. males in 1964 by age came from Keyfitz and Flieger [15].

The data on ℓ_x and ${}_na_x$ from Keyfitz and Flieger [15] for 1964 U.S. males were used to calculate ${}_nN_x$ (usually denoted ${}_nL_x$), which is the life table number of years lived before from ages x to $x+n$ [16]. The calculation of ${}_nM_x$ (the life table years lived after from ages x to $x+n$) then followed exactly the procedure of Spiegelman [17].

Since the expected present value of future earnings for men of each age in 1964 does not enter directly into Eqs. 6 or 9, the estimates by Rice and Cooper [18] could not be used. Rather, u_x, the average income of a male entering the age interval starting at x, was estimated from data presented in Rice (ref. 4, pp. 89, 117) as $u_x = nG_xE_x/{}_nL_x$. Here n is the duration in years of the age interval starting at x, G_x is S. Garfinkle's "Table of Working Life: Males, 1960," as reported by Rice (ref. 4, p. 117, her column 2), ${}_nL_x$ is taken directly from the 1959–61 U.S. male life table (ref. 15, p. 152), and E_x is the full-time annual mean earnings of male workers employed in 1963, based on unpublished Bureau of the Census tabulations as reported by Rice (ref. 4, p. 117, her column 4). Since Rice deflated her G_x entry for the 10–14 age interval by a factor of two, I have reinflated her entry before calculating u_x. The duration n of the last age interval, from 85 up, was assumed to be 10 yr, since in 1964 the expectation of life of U.S. men reaching 85 was nearly 5 yr. The estimates of u_x for 1964 obtained by the above procedure are thus an amalgam of data from 1960 and 1963 and hence only a first approximation.

Integrals were replaced by sums over the standard age categories of the abridged life table. Thus Eq. 10 became

$$P = \sum_{x=0}^{85} {}_nK_x \cdot P_x \tag{A1}$$

where

$$P_x = \sum_{y=x}^{85} \left(\frac{1}{1+i}\right)^{y-x+(n'-n)/2} \frac{u_y \cdot {}_{n'}N_y \cdot n \cdot P_{x,y}}{{}_nN_x \cdot n'} \tag{A2}$$

and

$$P_{x,y} = \frac{{}_{n'}M_y}{{}_nM_x} \bigg/ \frac{{}_{n'}N_y}{{}_nN_x} - 1$$

and n is the duration in years of the age interval starting at x, and n' is the duration of the interval starting at y. The age-specific curative benefits C_x and aggregated C were calculated from Eqs. A2 and A1 after replacing $P_{x,y}$ by $C_{x,y} = \log(1 + P_{x,y})$. ${}_nK_x$ came from Keyfitz and Flieger [15, p. 163].

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